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Observations of the Non-Thermal X-ray Emission from the Galactic Supernova Remnant G347.3-0.5

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Abstract. G347.3-0.5 (RX J1713.7-3946) is a member of the new class of shell-type Galactic supernova remnants (SNRs) that feature non-thermal components to their X-ray emission. We have analyzed the X-ray spectrum of this SNR over a broad energy range (0.5 to 30 keV) using archived data from observations made with two satellites, the Röntgensatellit (*ROSAT*) and the Advanced Satellite for Cosmology and Astrophysics (*ASCA*), along with data from our own observations made with the Rossi X-ray Timing Explorer (*RXTE*). Using a combination of the models EQUIL and SRCUT to fit thermal and non-thermal emission, respectively, from this SNR, we find evidence for a modest thermal component to G347.3-0.5's diffuse emission with a corresponding energy of $kT \approx 1.4$ keV. We also obtain an estimate of 70 TeV for the maximum energy of the cosmic-ray electrons that have been accelerated by this SNR.

1. Introduction

The X-ray luminous Galactic supernova remnant (SNR) G347.3-0.5 (RX J1713.7-3946) was discovered during the Röntgensatellit (*ROSAT*) All-Sky Survey (Pfeffermann & Aschenbach 1996). Subsequent studies of this SNR's X-ray properties (Koyama et al. 1997; Slane et al. 1999) revealed that most of its X-ray emission is non-thermal and very likely produced by the synchrotron process. G347.3-0.5 therefore becomes a member of a new class of young shell-type SNRs that feature non-thermal components to their X-ray emission. Other members of this class include Cas A (Allen et al. 1997), SN 1006 (Koyama et al. 1995, Allen et al. 2001) and G266.2-1.2 (Slane et al. 2001). TeV gamma rays have been detected from the X-ray luminous northwestern rim of this SNR (Muraishi et al. 2000), making G347.3-0.5 only the third SNR (besides SN 1006 and Cas A) where such high-energy emission is detected. The presence of this emission suggests that acceleration of cosmic-ray electrons is taking place along this rim, and that additional study of this SNR's X-ray emission may lead to new insights on how SNRs act as cosmic-ray particle accelerators.

In order to analyze the X-ray properties of G347.3-0.5 in more detail, as well as to study how cosmic-ray particles are accelerated by this SNR, we observed this source using the Rossi X-ray Timing Explorer (*RXTE*). We supplemented the data from these observations with publicly available data from observations that were made of G347.3-0.5 by two other X-ray satellites, *ROSAT* and the Advanced Satellite for Cosmology and Astrophysics (*ASCA*). Parameters for the X-ray observations used in this analysis are listed in Table 1. By combining the data from all three satellites, we have sampled the X-ray emission from this SNR over the energy range of 0.5 through 30 keV.

Table 1. Summary of X-ray Observations of G347.3-0.5

Satellite	Instrument	Observed Portion of G347.3-0.5	RA (J2000.0) (h m s)	Dec (J2000.0) (° ′ ″)	Exposure Time (Seconds)
ROSAT	*PSPC*	All	17 13 33.60	−39 48 36.0	2758
ASCA	*GIS*	NW Rim	17 12 17.76	−39 35 30.8	20337
		SW Rim	17 12 53.76	−39 54 23.4	18562
		NE Region	17 14 28.32	−39 35 26.2	16220
		SE Region	17 15 41.52	−40 02 25.8	40153
RXTE	*PCA*	All	17 14 11.04	−39 50 31.2	45000

2. Analysis

Previous analyses of the X-ray emission from G347.3-0.5 have considered only the *ROSAT* observations (Pfeffermann & Aschenbach 1996) or a combination of the *ROSAT* and *ASCA* observations (Slane et al. 1999). In the latter work, spectral fits were made to the X-ray luminous northwestern and southwestern rims as well as the entire SNR, and simple power-laws were found to adequately model both the emission from the rims as well as from the SNR itself.

After extracting spectra for the SNR as observed by all three satellites, spectral fitting was performed using the XSPEC software package. We first tried fitting the whole X-ray spectrum with the power-law fits obtained by Slane et al. 1999. We also used the SRCUT model (Reynolds 1996, Reynolds & Keohane 1999) to fit the data: this model fits a synchrotron spectrum from an exponentially cut-off power-law distribution of electrons in a uniform magnetic field. The corresponding relativistic electron energy spectrum can be expressed as

$$N_e(E) = KE^{-(2\alpha+1)}e^{\frac{-E}{E_{max}}}, \tag{1}$$

where K is a normalization constant derived from the observed flux density of the SNR at a frequency of 1 GHz, α is the observed radio spectral index of the SNR and E_{max} is the cut-off electron energy. A crucial advantage of the SRCUT model is that two of the parameters – K and α – are constrained by radio observations. In addition, the model returns a value for the break frequency ν_{break} of the electron energy spectrum, and an estimate for the maximum energy of the accelerated electrons can be made based on the value for this frequency.

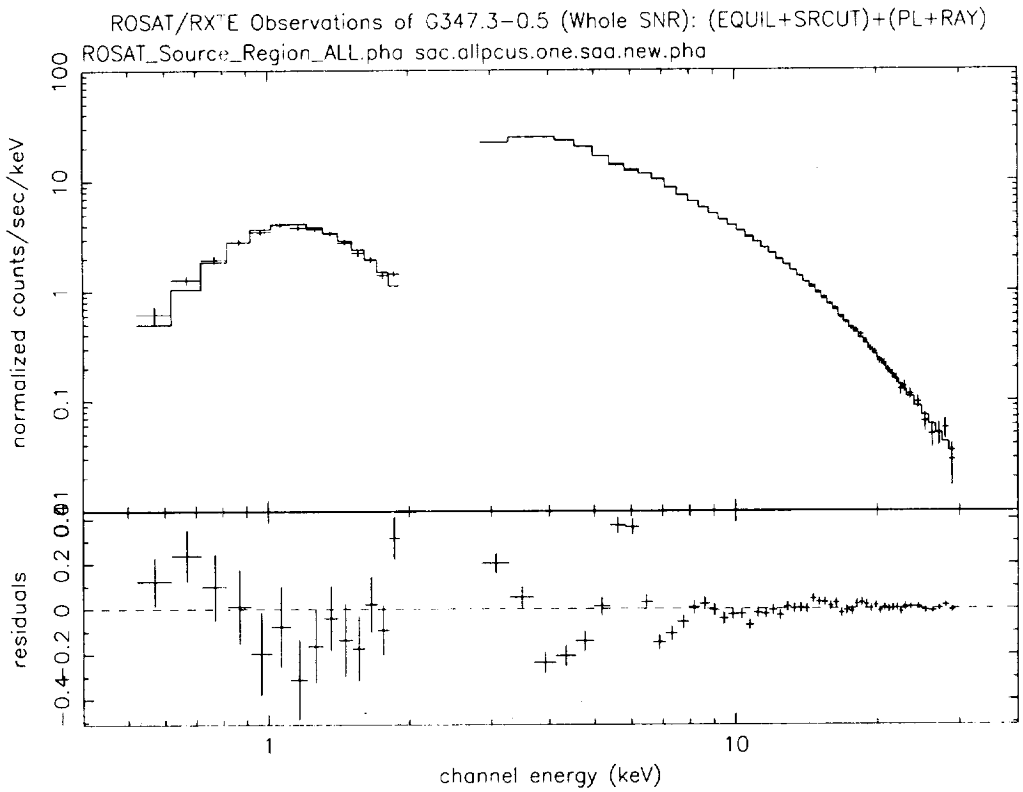

Figure 1. *ROSAT PSPC* and *RXTE PCA* observations of the diffuse emission from G347.3-0.5 over the energy range 0.5 through 30 keV.

Lastly, we note that G347.3-0.5 lies within the Galactic Ridge, which contributes a considerable amount of background emission to the *RXTE* observations. We modeled this emission using a two-component model (RAYMOND-SMITH and POWER LAW) with the parameters determined by Valinia & Marshall (1998) from their *RXTE* observations of this region ($kT = 2.9$ keV and $\Gamma = 1.8$). To help improve the fit and search for thermal emission from the SNR, we included a thermal equilibrium ionization model (EQUIL) in the fitting process. See Figure 1 for the fit to the SNR's diffuse emission.

3. Results and Conclusions

The results of this work may be summarized as follows:

1) Remarkably good fits (a reduced χ^2 of 1.9 for 487 degrees of freedom for all of the data sets in Table 1) to the X-ray spectrum of G347.3-0.5 as observed by the *ROSAT*, *ASCA* and *RXTE* satellites have been obtained by using a combination of non-thermal and thermal models (SRCUT and EQUIL) in XSPEC (see Table 2). The X-ray spectrum of G347.3-0.5 at energies higher than 8 keV cannot be adequately fit by simply extending the power-law fits presented by Slane et al. 1999.

Table 2. Best-Fit Parameters for *SRCUT* + *EQUIL* Model

Section of G347.3-0.5	n_H (10^{22} cm^{-2})	α^a	$\nu_{break}{}^a$ (10^{17} Hz)	K^a (Jy at 1 GHz)	kT^b (keV)
NW Rim	0.77±0.01	0.4996±0.0002	1.4578±0.005	1.787±0.011	1.375±0.016
SW Rim	0.61±0.02	0.5143±0.0003	2.4235±0.013	0.907±0.007	"
NE Region	0.49±0.02	0.5341±0.0003	2.9269±0.021	0.980±0.009	"
Diffuse	0.51±0.01	0.5000±0.0002	2.2751±0.004	1.989±0.005	"

[a] *SRCUT* fit parameter with single parameter 1σ errors.
[b] *EQUIL* fit parameter with single parameter 1σ errors.

2) We have found evidence for modest thermal emission from this SNR. The energy of this thermal component is rather large ($kT \approx 1.4$ keV) and appears to be associated with the diffuse emission from the SNR rather than the X-ray luminous rims. At an assumed distance of 6 kpc, the corresponding ambient density is $n_H \approx 0.02$ cm^{-3}, consistent with the works of other authors (Slane et al. 1999, Ellison et al. 2001).

3) For the range of break frequencies determined for the different portions of G347.3-0.5 (1.5 through 2.9 $\times$ 10^{17} Hz), we follow the example of Reynolds & Keohane (1999) and calculate a maximum electron energy of $\approx$ 70 TeV, assuming an ambient magnetic field strength of 10 μG. This result is larger than the maximum electron energy calculated with different models for G347.3-0.5 by Ellison et al. 2001.

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